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**Time Based Subjective Evaluations of Seated
Cushion Comfort**

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14. ABSTRACT The detrimental effects of prolonged sitting during long-duration flights include deep vein thrombosis, pressure sores, and decreased awareness and performance. Oftentimes, the cushion is the only component of the seat system that can be modified to mitigate these effects. In addition, it is the cushion that has a direct connection to the seated subject, and thus directly influences his perception. Typically questions are asked of the subject to evaluate his current state of comfort. However, care should be taken when designing such studies that the environment of use is taken into consideration. One such important variable is how long the subject will be expected to sit in a particular seat position. Several studies were undertaken at Wright-Patterson Air Force Base (WPAFB) in Dayton, Ohio to evaluate the long term cushion comfort of a diverse population. Test times ranged from four to eight hours of sit time during each test session. Variables measured included seat interface pressure, oxygen saturation in the lower extremities, muscle fatigue along the back, a cognitive performance task, and subjective evaluations. This study investigated the effect of time on the subjective evaluations from four different studies. It was found that the subjective variables most influenced by time were center/lower back and buttocks, while the shoulder and lower leg variables had no time effect. When the subjects were asked to rate their cushion preferences, it was found that approximately six hours were necessary before the subjects' opinions of the cushions no longer changed. This finding is important for tests where the Air Force evaluates cushion options for different missions that may last nine hours or longer. These results and research are relevant to the seating industry whether they are for office, transportation or industrial environments as subjective evaluations are often conducted in order to obtain the best choice for the setting. However, it is important to know before these surveys are conducted, how long a subject should sit in the seat before opinions are collected.					
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TABLE OF CONTENTS

PREFACE	v
INTRODUCTION	1
BACKGROUND	1
METHODS	2
RESULTS	6
Cushion Ranking.....	6
Subjective Survey	8
Physical Condition Rating	12
DISCUSSION	13
CONCLUSION	14
REFERENCES	15

LIST OF FIGURES

Figure 1. Study 1 test station	3
Figure 2. Study 3 test station	4
Figure 3. Study 4 test station	4
Figure 4. Study 5 test station	5
Figure 5. Self reported cushion rank order for center back discomfort	6
Figure 6. Self reported cushion rank order for lower back discomfort	7
Figure 7. Self reported cushion rank order for buttocks discomfort	8
Figure 8. Self reported discomfort rating for center back	9
Figure 9. Self reported discomfort rating for lower back	10
Figure 10. Self reported discomfort rating for buttocks	11
Figure 11. Subjects' average physical condition for both weight cases in study 4	12
Figure 12. Subjects' average physical condition for the four cushions in study 4	13

PREFACE

The cushion comfort tests and data analysis described in this report were accomplished by the Biomechanics Branch, Human Effectiveness Directorate of the Air Force Research Laboratory (AFRL/HEPA) at Wright-Patterson Air Force Base, Ohio. This research was supported in part by an appointment to the Research Participation Program at the Air Force Research Laboratory, Human Effectiveness Directorate, Biomechanics Branch, Wright Patterson AFB, administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and AFRL/HEP.

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INTRODUCTION

The purpose of this study was to determine the amount of seat time necessary for study subjects to effectively evaluate seat cushion interfaces and determine their discomfort level. The three main questions addressed were: 1) When does a subject's discomfort rating for a seat cushion stabilize and no longer change? 2) When does a subject's rank ordering of different cushions no longer change? 3) What body regions are most influenced by time? These questions are necessary for effective study design and evaluation of seat cushions for the US Air Force. AFRL is currently leading a cushion design program to enhance pilot performance during extended missions. The average length of time for an extended mission for various fighter aircraft is approximately 9 hours. Any cushion design will have to take into account this obvious time effect.

This study is part of an overall effort to define seat and cushion parameters that will maximize comfort and performance without jeopardizing ejection safety. This report also serves as a summary of subjective data collected from previous testing. Previous work includes a pilot study conducted in 1999 in which 5 males were monitored for a 4-hour sit duration (Pint *et al.*, 2002). This study indicated the need for long-duration monitoring to gain a realistic understanding of the long-term effects on the operator's responses. The pilot study also led to improvements for the first 8-hour sit duration study conducted in 2003 in which a larger, more diverse subject panel was observed on 4 cushion types (Stubbs *et al.*, 2003). The 2003 study highlighted the correlations that do exist in objective seated pressures and subjective comfort levels. The tools and measurement techniques employed in the current effort were selected based on the results of the first two studies. The current effort expanded upon the previous studies by introducing additional variables including active stimulation, increased measurement frequencies, and new measurement techniques. These techniques included monitoring the percent change in lower extremity blood oxygen saturation levels to provide an estimation of blood flow behavior and monitoring low back and shoulder muscular fatigue. These factors were selected because they are suspected of being significant contributors of discomfort during seated long-term flight.

BACKGROUND

Ejection seat cushions in current U.S. Air Force aircraft are not optimized for comfort during extended missions. With combat bomber crew missions during Operation Enduring Freedom reaching over 40 hours in length, it has become increasingly important that crewmember seat comfort be improved. These improvements are critical to enhance both physical endurance and combat effectiveness.

Shortcomings of existing ejection seat cushions have been documented by researchers (Cohen, 1998; Hearon and Brinkley, 1986; Severence, 1997) and through interviews conducted with pilots and flight surgeons (Pint, 1999). The most common complaints were buttock and lumbar spine soreness, tingling in the extremities, numbness and overall fatigue. The discomfort experienced during extended missions has several causes. The materials used in ejection seat

cushions are not selected based on their comfort properties; but rather they are selected for their performance in limiting spinal injuries during ejection. Cockpit space restrictions associated with most ejection seat equipped aircraft severely restrict the seat occupant's ability to reposition during flight. Ejection seat dimensions and contours are fixed, causing accommodation problems, especially for large and small occupants. Previous research has shown that all of these problems can be addressed (Cohen, 1998; Severence, 1997; VanIngen-Dunn and Richards, 1992). However, completely eliminating all occupant discomfort would likely require an entire seat system redesign or a limit in the duration of the mission. Oftentimes, the only component to which feasible, cost-effective modifications can be made is the ejection seat cushion.

Recent studies have shown that cushions made from various densities of Confor™ provide superior impact protection and improved occupant comfort (Cohen, 1998; Hearon and Brinkely, 1986; Perry, 1997; Perry *et al.*, 2000) compared to foam rubber or polyurethane combinations. In fact, a replacement cushion was approved for use in the B-2 and other ACES II configurations based upon impact testing and an evaluation of cushions with different densities of Confor™ and various surface contours. However, in a recent evaluation of the replacement B-2 cushions, it was determined that no single cushion could be designed to accommodate the entire anthropometric range. It was recommended that individual cushions be fitted for each pilot (Cohen, 1998). Another technique that has been used extensively for wheelchair users is active stimulation incorporated within the cushion using pulsation or vibration devices. A qualification study was performed on a pulsating seat cushion and adjustable lumbar pad combination for U.S. Navy aircraft. The results showed no increased injury risk, but also highlighted the need for further research in this area (Cantor, 1974). A Small Business Innovation Research Phase 1 program sponsored by the U.S. Air Force investigated the possibility of active stimulation, variable contoured cushion and headrest surfaces, and layering of materials to eliminate discomfort during extended missions (Happ, 2000).

METHODS

To investigate the effect of time, several studies conducted at the Biomechanics Branch (HEPA) of the Air Force Research Laboratory (AFRL) at Wright-Patterson AFB in Dayton, Ohio, were queried for their subjective results. These studies varied both in duration (4-8 hours) and seat setup. Common traits of all studies were the collection of pressure map data and subjective survey data to assess the general opinion of the test subjects. Also, the test subjects remained seated during the entire test period with no breaks in between. All studies were approved by the Institutional Review Board (IRB) at Wright-Patterson AFB and two of the studies were also approved by the IRB of Wright State University. A brief description of the test methods for each follows.

Study 1: 1999 4 Hour duration study: Five male subjects took part in this study (Pint *et al.* 2002). All were active-duty military members assigned to AFRL/HEPA. The subjects were seated in an ACES II ejection seat and rudder pedal assembly was mounted to an adjustable platform to simulate the vertical adjustment range of the ACES II in the F-15 configuration. The seat was mounted with a rail angle of 17° aft of vertical with the seat pan inclined 6° from the horizontal. The rudder pedal assembly was fixed vertically but had the full range of horizontal adjustment (Figure 1).



Figure 1. Study 1 test station

All subjects were dressed in Battle Dress Uniform (BDU) pants, T-shirt, and combat boots. The subjects' average height was 70 inches and average weight was 172 pounds. A PCU-15/P restraint harness was worn, but not connected to the seat's inertia reel straps. An HGU-55/P flight helmet was worn during all phases of testing.

At one-hour intervals during the test, subjects completed a survey to rank the level of discomfort experienced at various locations on their body. A five-point scale was used. A rating of 1 corresponded to "No Discomfort" and a rating of 5 corresponded to "Unbearable Discomfort".

Study 2: 2003 4 Hour duration study: Nine male civilian subjects participated in this study. The subjects were seated in an adjustable AIP-1221 seat mockup. Subjects were restrained to the seat with the shoulder harness and lap belt on the seat. A CWU-27/P flight suit was provided along with a HGU-55/P flight helmet for the subjects to wear during testing. The subjects' average height was 69.7 inches and average weight was 156.8 pounds.

A seated comfort survey was administered at the start of each session and hourly thereafter. The survey required subjects to rate the discomfort or pain on a 10-point scale where 1 was equivalent to "No Discomfort" and 10 was equivalent to "Unbearable Discomfort".

Study 3: 2003 8 Hour duration study: Twenty subjects, 8 male and 12 female, took part in this study (Stubbs *et al.* 2005). Subjects were active-duty military members, college students, or civilians. The subjects were seated in an ACES II ejection seat and rudder pedal assembly was mounted to an adjustable platform to simulate the vertical adjustment range of the ACES II in the F-15 configuration. The seat was mounted with a rail angle of 17° aft of vertical with the seat pan inclined 6° from the horizontal. The rudder pedal assembly was fixed vertically but had the full range of horizontal adjustment (Figure 2). All subjects were dressed in CWU-27/P flight suit and donned a HGU-55/P flight helmet for testing. The subjects' average height was 68.3 inches and average weight was 152.1 pounds.



Figure 2. Study 3 test station

A survey was administered to subjects at the start, middle, and end of each eight-hour test session. The survey was on a 1-10 scale with 1 corresponding to “No Discomfort” and a rating of 10 corresponded to “Unbearable Discomfort”.

Study 4: 2005 8 Hour duration study: Twenty-two subjects, 13 male and 9 female, took part in this study (Pellettiere *et al.* 2007, Parakkat *et al.* 2006). All were civilian volunteers who were pre-screened to ensure no pre-existing risk factors existed. The subjects were seated on an ACES II ejection test seat and foot block. The seat had a rail angle of 15° aft of vertical with the seat pan inclined 4° from the horizontal (Figure 3). Subjects wore civilian clothing and a HGU-55/P flight helmet was worn for each session. The subjects’ average height was 68.4 inches and average weight was 174.2 pounds.



Figure 3. Study 4 test station

A seated comfort survey was administered at the start of each session and every two hours thereafter. The survey required subjects to rate the discomfort or pain of individual body parts on a 12-point scale where 0 was equivalent to “No Discomfort” and 11 was equivalent to “Maximal Discomfort”.

Study 5: 2006 8 Hour duration study: Twenty-six subjects, 14 male and 12 female, took part in this study (Pellettiere *et al.* 2007). All were civilian volunteers who were pre-screened to ensure no pre-existing risk factors existed. The subjects were seated in an ACES II ejection seat mockup cockpit with foot pedal assembly mounted to an adjustable platform to simulate the vertical adjustment range of the ACES II in the F-16 configuration. The seat was mounted with a rail angle of 15° aft of vertical with the seat pan inclined 4° from the horizontal (Figure 4). Subjects wore civilian clothing and an automobile restraint lap belt was used to limit movement, no helmet was worn for this study. The subjects’ average height was 67.6 inches and average weight was 155.6 pounds.



Figure 4. Study 5 test station

A seated comfort survey was administered at the start of each session and every two hours thereafter. The survey required subjects to rate the discomfort or pain of individual body parts on a 12-point scale where 0 was equivalent to “No Discomfort” and 11 was equivalent to “Maximal Discomfort”.

Common traits of all studies were the collection of pressure map data and subjective survey data to assess the general opinion of the test subjects. Also, the test subjects remained seated during the entire test period with no breaks in between.

RESULTS

Cushion Ranking

Each subject was asked to rate their current level of discomfort. The absolute scale varied depending on the particular study from a 5 point to a 12 point scale. However, within a study, this discomfort scale could be used to rank the cushion options from best (score of 1) to worst (score of 4). Then these rankings could be collected over time and an average calculated to demonstrate how the subjects' preferences for each of the cushions varied.

Center Back: During Study 2, the rank order continued to change up to the test end point of 4 hours for cushions A and B and it appears the subjects preferred cushions D and C after hours 1 and 2 respectively (Figure 5). For Study 3, the order changed between 4 to 8 hours. In Study 4 the rank order remained constant for all cushions after hour 4. The rank order continued to change throughout the entire test for Study 5 although cushion C held constant from hour 6 to the end of hour 8. Overall, the subjects were not able to conclusively determine their seat cushion preference based upon their center back discomfort for Study 3 and 5, but Study 2 and 4 did reveal a cushion preference.

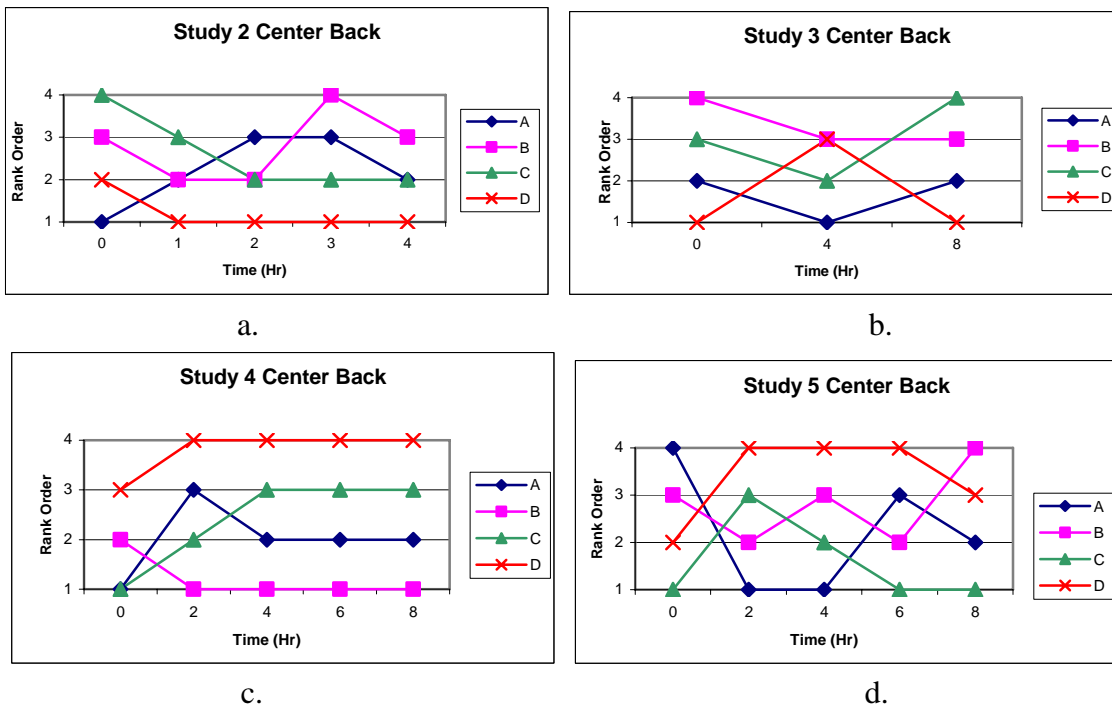


Figure 5. Self reported cushion rank order for center back discomfort
a. Study 2 (2003 4 Hour) b. Study 3 (2003 8 Hour)
c. Study 4 (2005 8 Hour) d. Study 5 (2006 8 Hour)

Lower Back: During Study 2, the subjects preferred cushions C and D after the first hour and throughout the test session (Figure 6). For Study 3, the order changed between 4 to 8 hours for all cushions. In Study 4 the rank order remained constant for cushions A and B after hour 4 and for cushions C and D after hour 6. The subjects in Study 5 remained constant on their preference for cushion B from hour 4 to the end of hour 8, while the rank order changed throughout the test session for all other cushions. Therefore, seat cushion preference based upon their lower back discomfort was discovered in 3 of the 4 studies evaluated.

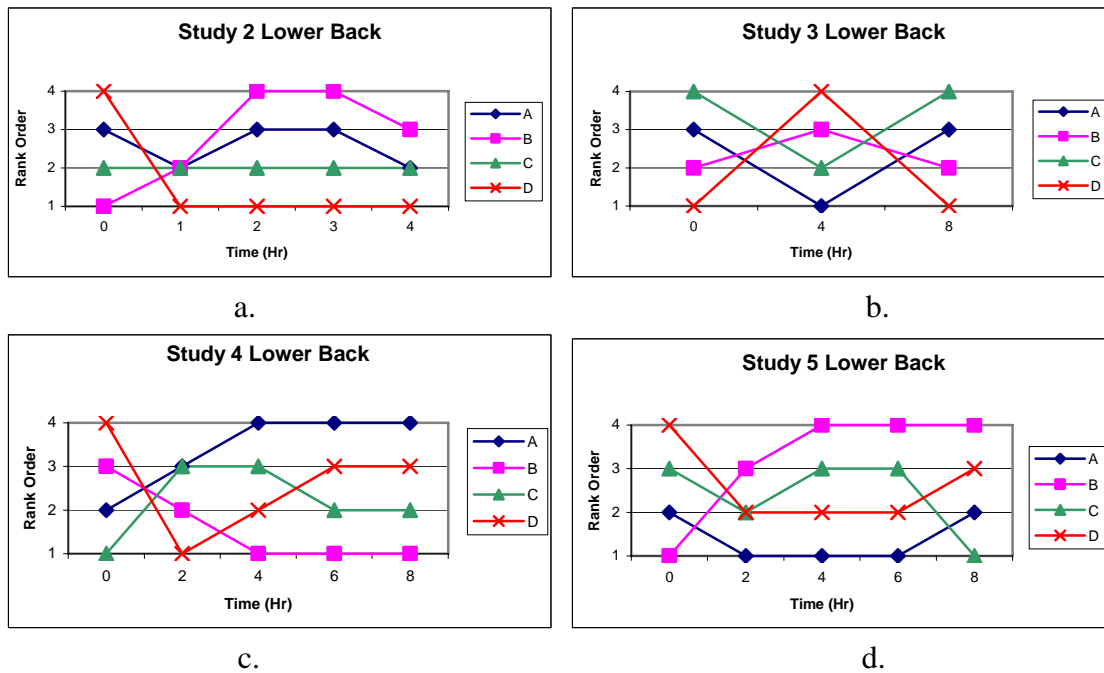


Figure 6. Self reported cushion rank order for lower back discomfort

a. Study 2 (2003 4 Hour) b. Study 3 (2003 8 Hour)
c. Study 4 (2005 8 Hour) d. Study 5 (2006 8 Hour)

Buttocks: For Study 2, it appears the subjects preferred cushion C from hours 2 to the end of the test (Figure 7). The seat cushion preference for Study 3 remained constant for cushions B, C, and D. At hour 3 the rank order stayed the same for cushions B and D. The rank order changed all cushions throughout Study 4 except for cushion A which remained constant after hour 6. For Study 5, the rank order remained constant from hours 6 to 8 for cushions A and D. Subjects were able to conclusively determine at least one seat cushion preference based upon their buttocks discomfort in all of the test conditions.

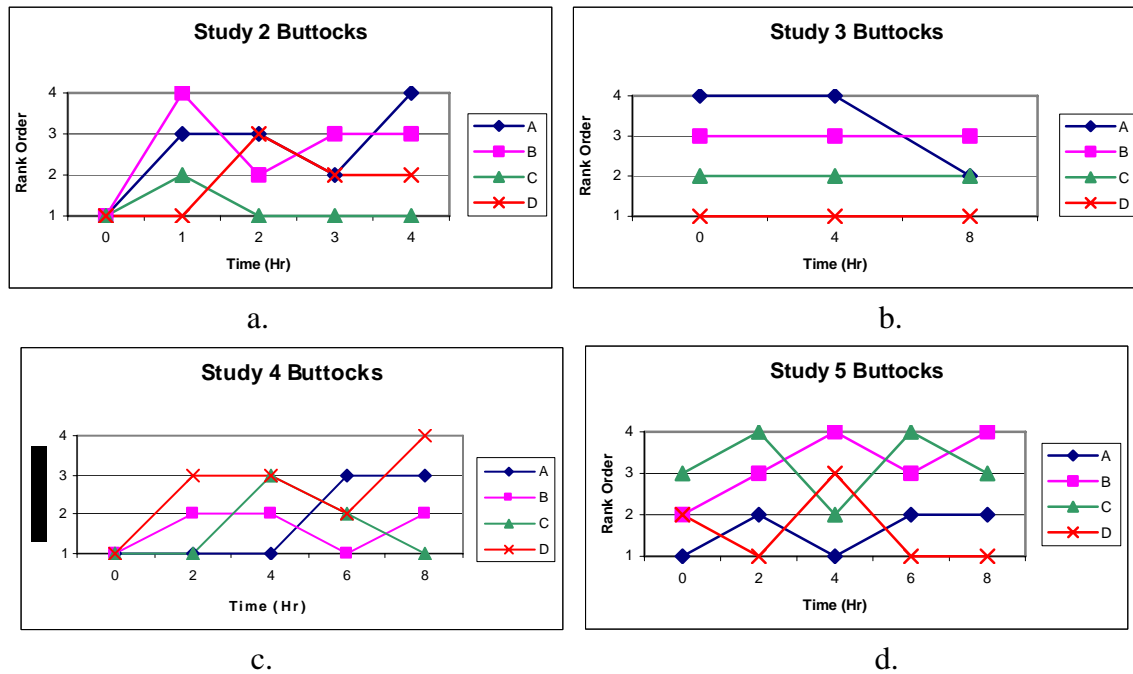


Figure 7. Self reported cushion rank order for buttocks discomfort
a. Study 2 (2003 4 Hour) b. Study 3 (2003 8 Hour)
c. Study 4 (2005 8 Hour) d. Study 5 (2006 8 Hour)

Subjective Survey

Each subject was asked to rate their current level of discomfort. The absolute scale varied depending on the particular study from a 5 point to a 12 point scale. For Study 2, subjects were divided by gender and then by weight case. Within the females, four subjects composed Weight Case 1 (<145 lbs) and five subjects composed Weight Case 2 (>145 lbs). Within the males, six subjects composed Weight Case 1 (<200 lbs) and seven subjects composed Weight Case 2 (>200 lbs). However, for the rest of the studies, the only distinctions made were between males and females.

Center Back Discomfort Rating: Center Back discomfort ratings are based on each subject's average discomfort for Right Middle Back, Middle Spine, and Left Middle Back (Figure 8). No discomfort was reported in beginning, but discomfort increased slightly throughout the day for both males and females. Excluding cushion D for females in Study 4, males and females have similar center back discomfort levels on average for both studies.

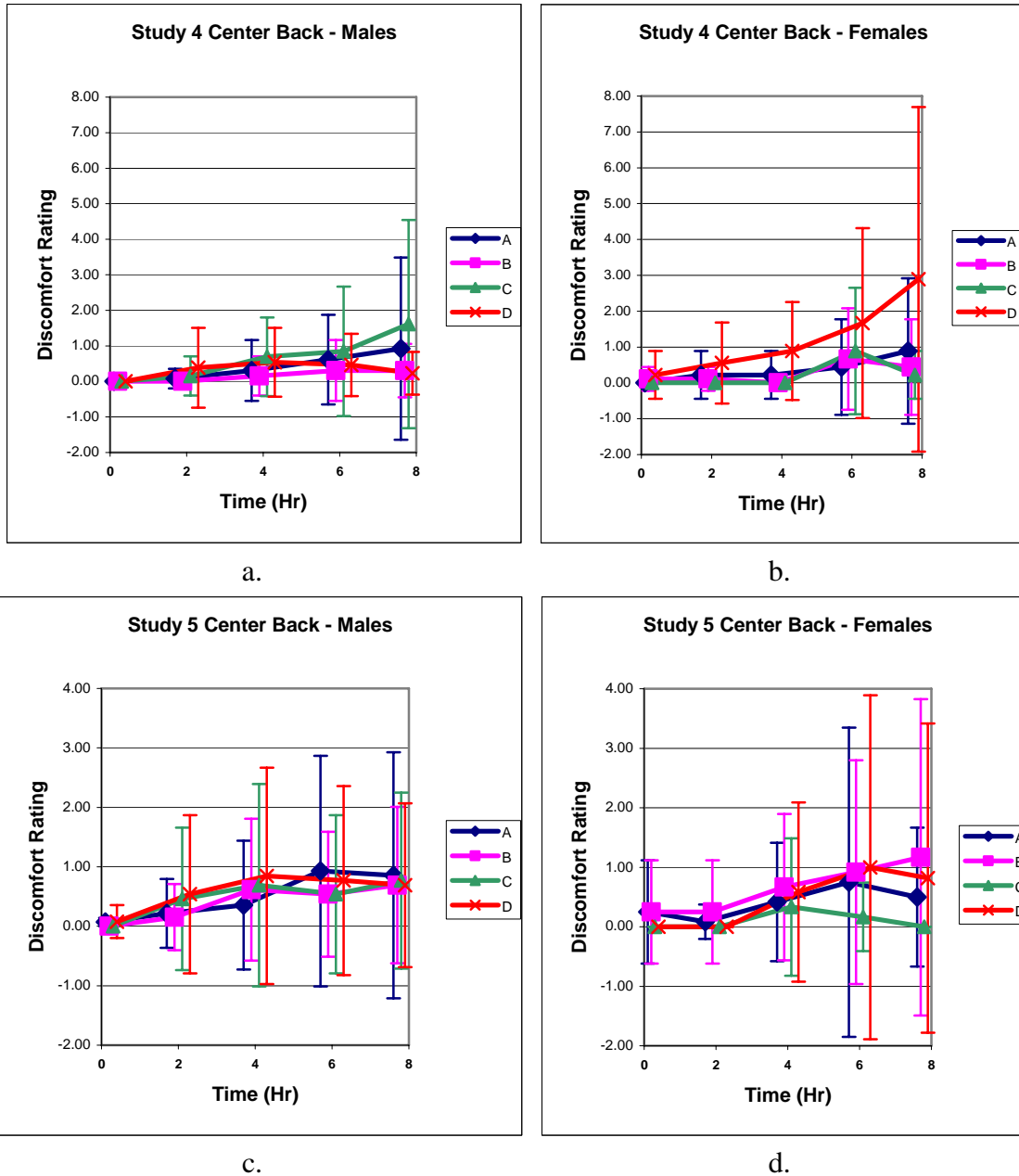


Figure 8. Self reported discomfort rating for center back
a. Study 4 – Males b. Study 4 – Females
c. Study 5 – Males d. Study 5 – Females

Lower Back Discomfort Rating: Lower Back discomfort ratings are based on each subject's average discomfort for Right Lower Back, Lower Spine, and Left Lower Back (Figure 9). No discomfort was reported in beginning, although discomfort increased slightly throughout the day for both males and females. The females did reveal a larger lower back discomfort rating on average than the males at hour 8 for most cushions for Study 4, while Study 5 showed more similar discomfort ratings.

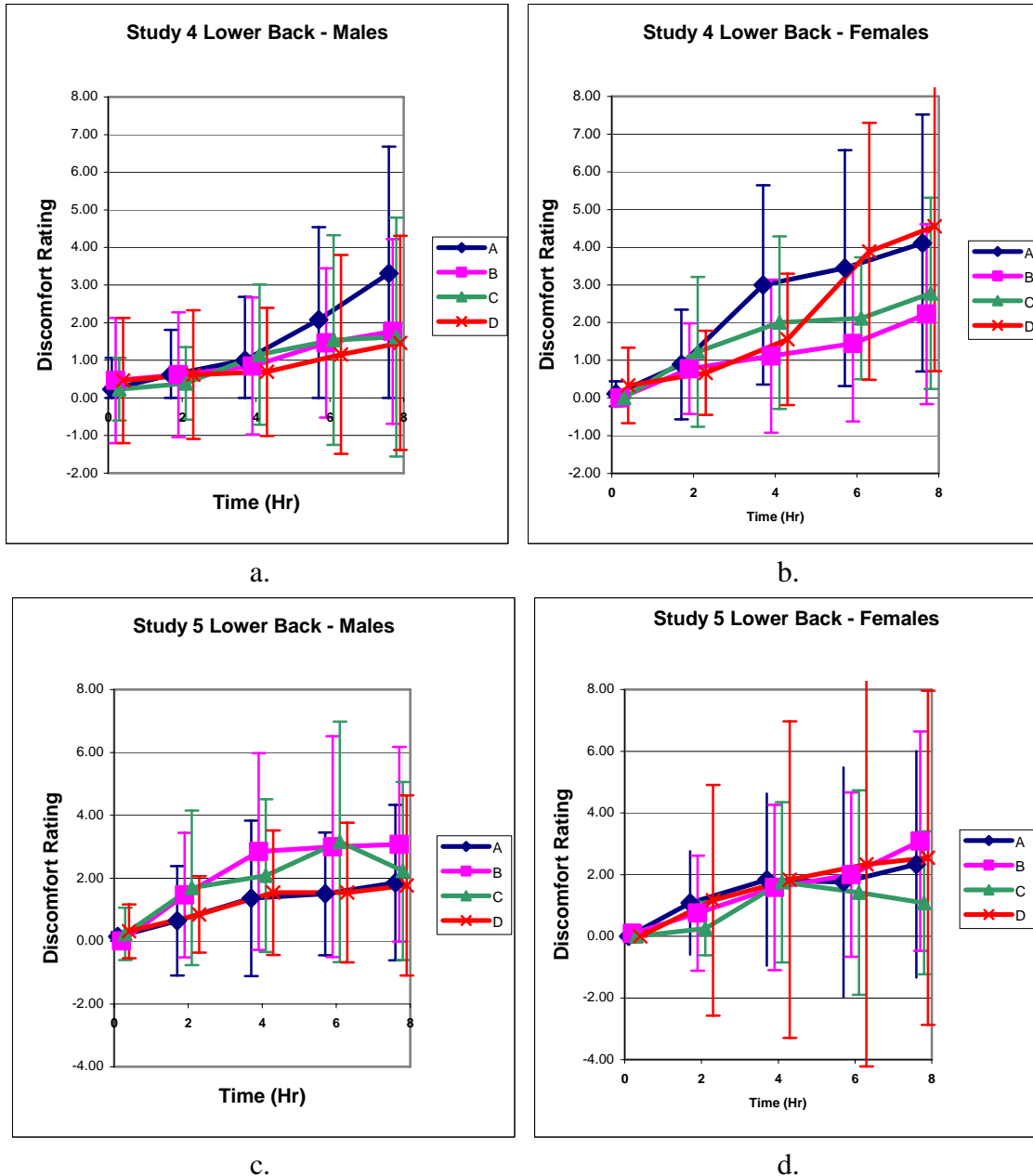


Figure 9. Self reported discomfort rating for lower back
a. Study 4 – Males b. Study 4 – Females
c. Study 5 – Males d. Study 5 – Females

When combining the scores for the center and lower back for Study 4 the ratings for the back showed a significant difference in time ($p = 0.001$). Both males and females reported no discomfort at the start of the session (Figures 8 and 9). However, the discomfort increased slightly during the 8-hour session for males and more for females, with an average increase of about 3 points (from no discomfort to moderate discomfort).

Buttocks Discomfort Rating: Buttocks discomfort ratings are based on each subject's average discomfort for Right Buttock and Left Buttock (Figure 10). No discomfort was reported in

beginning, but discomfort did increase throughout the day for both males and females. The females had a slightly higher discomfort rating than the males at hour 8 for most cushions. The ratings for the buttocks showed a significant difference for time ($p = 0.001$), sex ($p = 0.05$) and weight ($p = 0.02$). Both males and females reported no discomfort at the start of the session (Figure 10). However, the discomfort increased slightly during the 8-hour session for Male Weight Cases 1 and 2 and Female Weight Case 1. The discomfort increased for Female Weight Case 1 with an average increase of about 4 points.

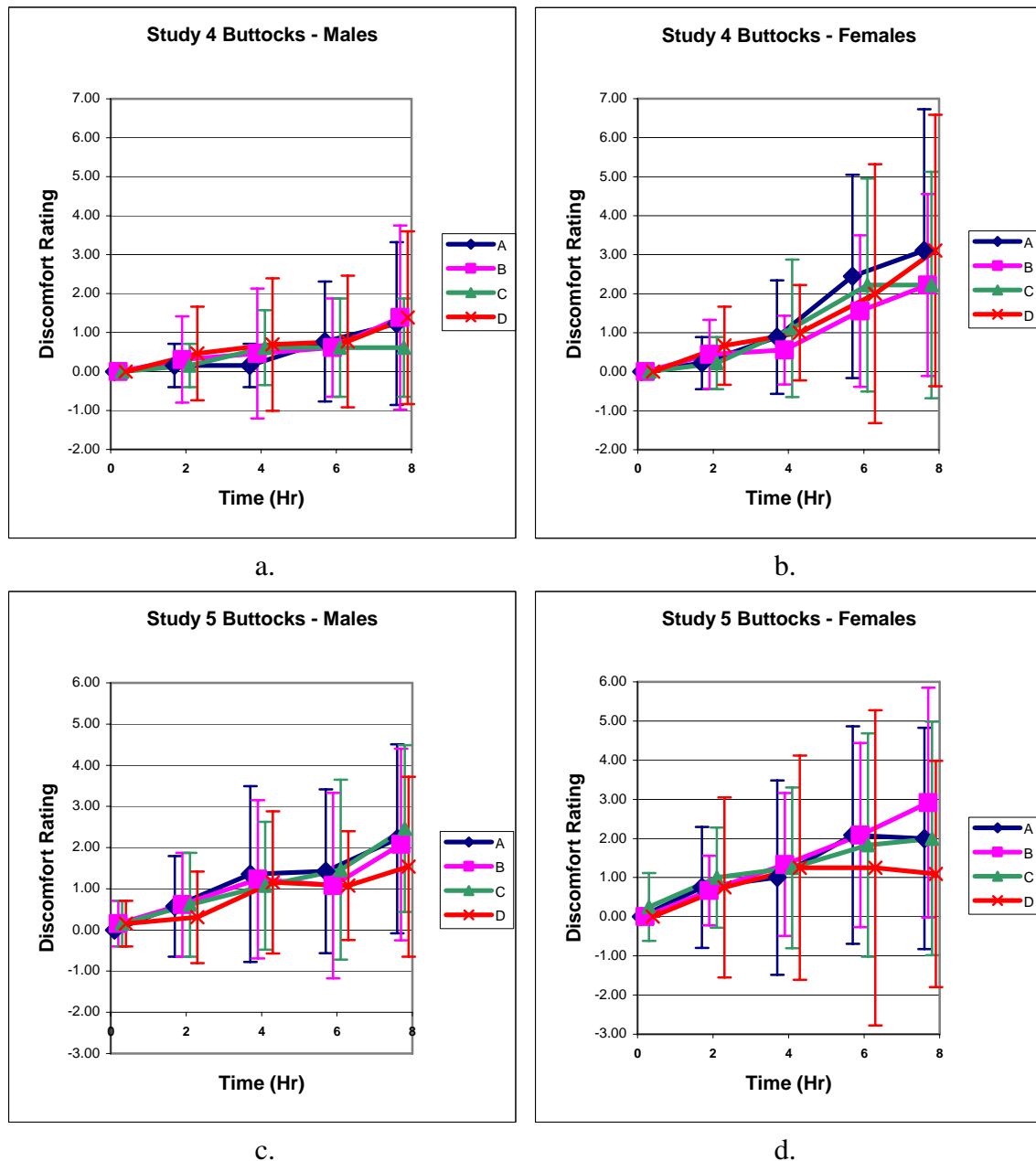


Figure 10. Self reported discomfort rating for buttocks
a. Study 4 – Males b. Study 4 – Females
c. Study 5 – Males d. Study 5 – Females

Physical Condition Rating

During Study 4, the survey required the subject to rate the physical condition of the whole body on a 10-point scale where 1 was equivalent to “feeling bad” and 10 was equivalent to “feeling great”. A significant effect ($p = 0.04$) was found for the physical condition of the subjects for the combined variables time, sex and weight case. The physical condition decreased over time, starting from good to OK (Figure 11). The physical condition decreased the same amount for both males and females. Females started with a somewhat lower physical condition rating when compared to the male subjects. The second weight case within the female subjects started with a lower physical condition and had a lower rate of decrease in physical condition over the 8-hour session. No difference in physical condition was found among the various seat cushions, indicating that all seat cushions performed similarly (Figure 12).

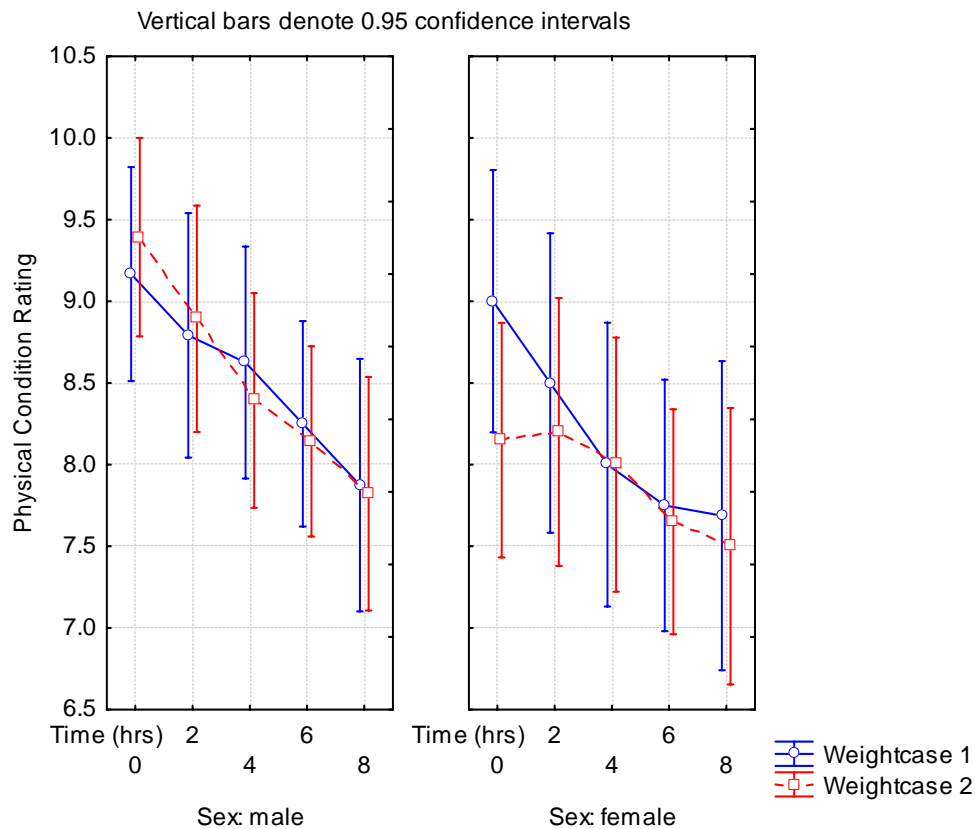


Figure 11. Subjects' average physical condition for both weight cases in study 4

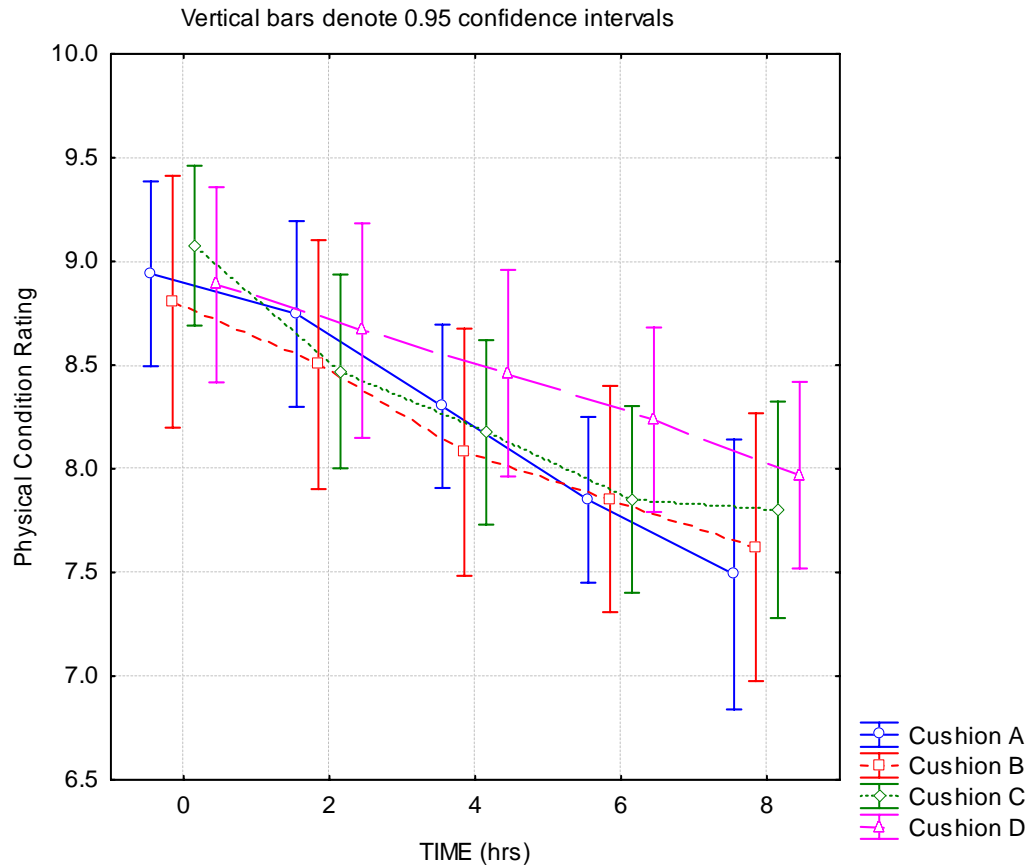


Figure 12. Subjects' average physical condition for the four cushions in study 4

DISCUSSION

A couple of points need to be made here. The data presented focused solely on the subjects reporting of their condition and preferences. For instance, data was not presented as to why one subject would prefer a specific cushion. Also, any discomfort was self reported and was not correlated to any physiological condition such as fatigue or numbness. Instead the aim was to investigate how the subject's perceptions would change over time. With this in mind, it can be said that the average amount of time for a subjects opinions to stabilize was 6 hours. However, this was for their ability to rate discomfort for their center and lower back and their buttocks. While investigating these data, it was found that discomfort for the shoulders and lower legs had little if any effect based upon time.

The important aspect for the US Air Force is that if a seating system is going to be based upon subjective evaluations and pilot preferences, then an appropriate length of time should be used. For instance, if flight sorties are only lasting 1-2 hours, then it is not necessary to conduct 8 hour tests. In the automotive and office seating industry, preferences are typically made over a 5-10 minute acquaintance period such that would occur during a test drive or while visiting a showroom with several seats. In these cases, the subjects would seldom spend 8+ hours confined

to the seat. While driving times can last that long, because of the need to refuel the vehicle as well as take restroom breaks, trip segments seldom last that long. In the office environment, people are seldom confined to their seats because of other necessary tasks. It is true for some job functions that extended sit time may be necessary, and in those cases, appropriate test periods should be utilized.

The average duration of a long flight mission is approximately 9 hours. Because of this, it would not be appropriate to make a seat selection based upon an initial reaction or sit tests that only lasted for a few hours. A good example of this is during Study 2 (Figure 6) for the ranking based upon the lower back. In the initial reaction, Cushion D was rated as the worst, but after the first hour it was then consistently ranked as the best. As the data showed, the subjects' preferences changed over time and did not begin to consistently stabilize until after 6 hours. While it may be true that often times the preferred choice came out earlier than 6 hours, in some cases the preferred options did not become apparent until at least 6 hours of testing. It is important to know how some of those other cushions perform as the most preferred cushion, may not always be the best choice because of other factors such as cost, safety, or durability. To select an appropriate cushion, other factors must also be considered, such as affordability and if there were any physiological effects from one cushion to another. Thus, subjective preference is only one variable and a proper ranking system is needed in order for a designer or manager to make appropriate trade-offs.

CONCLUSION

With all these considerations, 6-8 hour sit tests are appropriate for the selection of seat cushions for ejection systems where the pilots are expected to be in the aircraft for that length of time or more.

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